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Grid Generation for Fusion Applications

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Magnetized plasma

- An extremely anisotropic medium :
 - Transport coefficients in the parallel (to the magnetic field) and perpendicular directions differ by several order of magnitude : $k_{//}/k_{\perp} \sim 10^9$
 - Dynamics is completely different in the parallel and perpendicular direction : incompressible in the perp direction, compressible (and supersonic in the SOL) in the parallel direction : plasma slides along the magnetic field lines
- Plasma - wall interaction (Bohm's boundary condition) : Plasma enter into the wall at supersonic velocity :

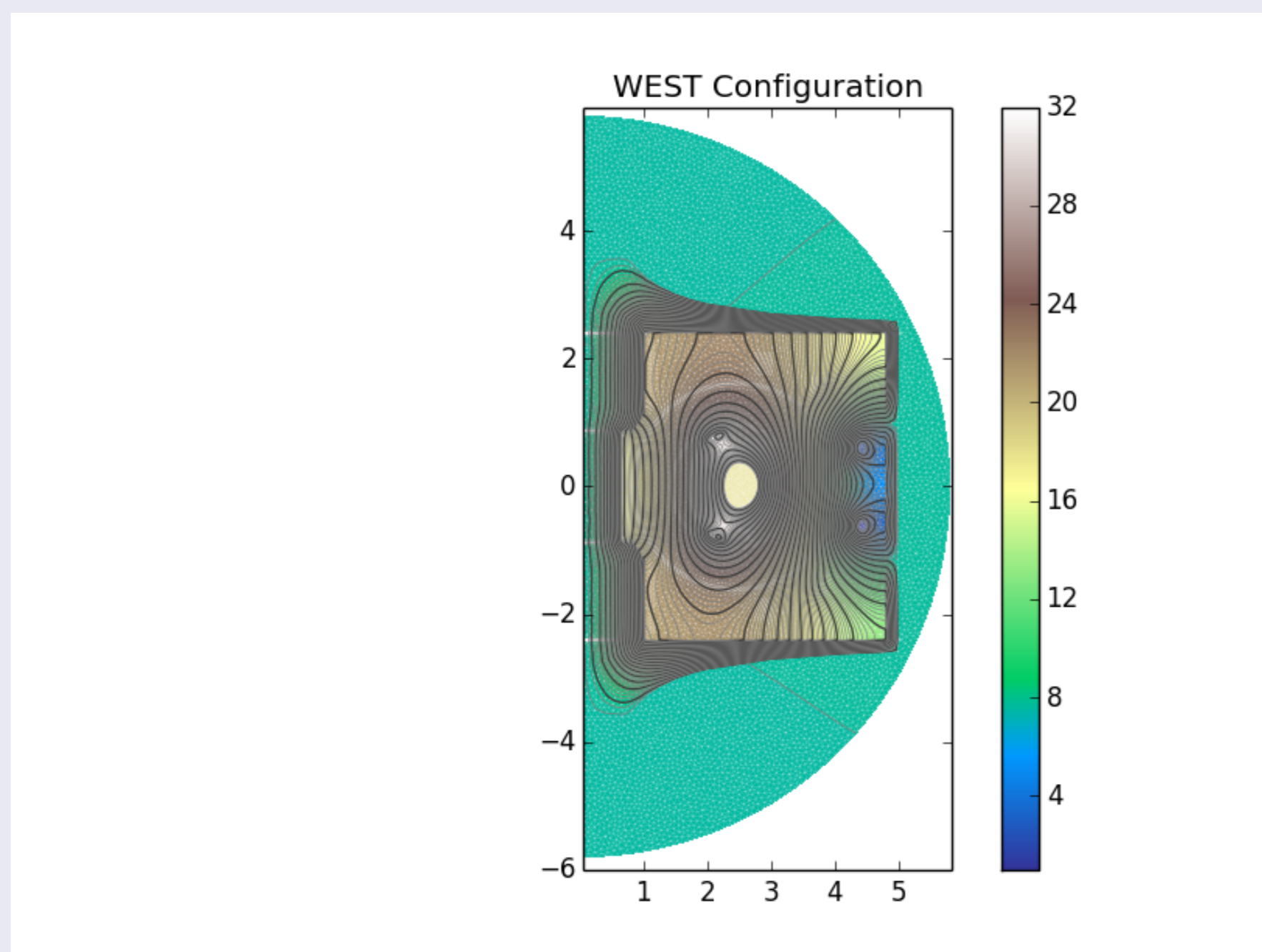
In magnetized plasma, plasma flows along the magnetic field lines

Meshes adapted to magnetic flux surfaces

Grad-Shafranov solvers

For realistic geometries, magnetic field has to be computed by numerical Grad-Shafranov solvers

$$-\nabla \left(\frac{1}{\mu r} \nabla \psi \right) = \begin{cases} \mathbf{J}(x, \psi) & \text{plasma} \\ \mathbf{J}(\text{voltage}, \partial_t \psi) & \text{coils} \\ 0 & \text{elsewhere} \end{cases}$$



Block-structured grid

- Block-structured meshes :
 - Identify the sub-domains (blocks-patches) Ω_n
 - Construct the mappings between logical grid $[0, 1] \times [0, 1]$ and physical Ω_n
- How many blocks and definition of the patches ?
This is a **segmentation problem** :
Given a domain Ω : Find a number n and n patches Ω_n such that :
$$\Omega = \cup \Omega_n \text{ with } \overset{\circ}{\Omega}_n \cap \overset{\circ}{\Omega}_m = \emptyset$$
and there exists a one to one mapping between Ω_n and the the unit square :
$$\exists \phi_n : [0, 1] \times [0, 1] \leftrightarrow \Omega_n$$
- for flux surface aligned grid, the segmentation problem can be solved by **Morse theory**

Segmentation Problem and Morse Function

f is a Morse function if all its critical points are regular.

Critical points
Let \mathcal{C}^r be the space of $r \geq 2$ differentiable scalar field defined on Ω . $\mathbf{p} \in \Omega$ is a critical point of f if $\nabla f(\mathbf{p}) = 0$.

Regular Critical points
A critical point is regular if the Hessian of f at \mathbf{p} is invertible.

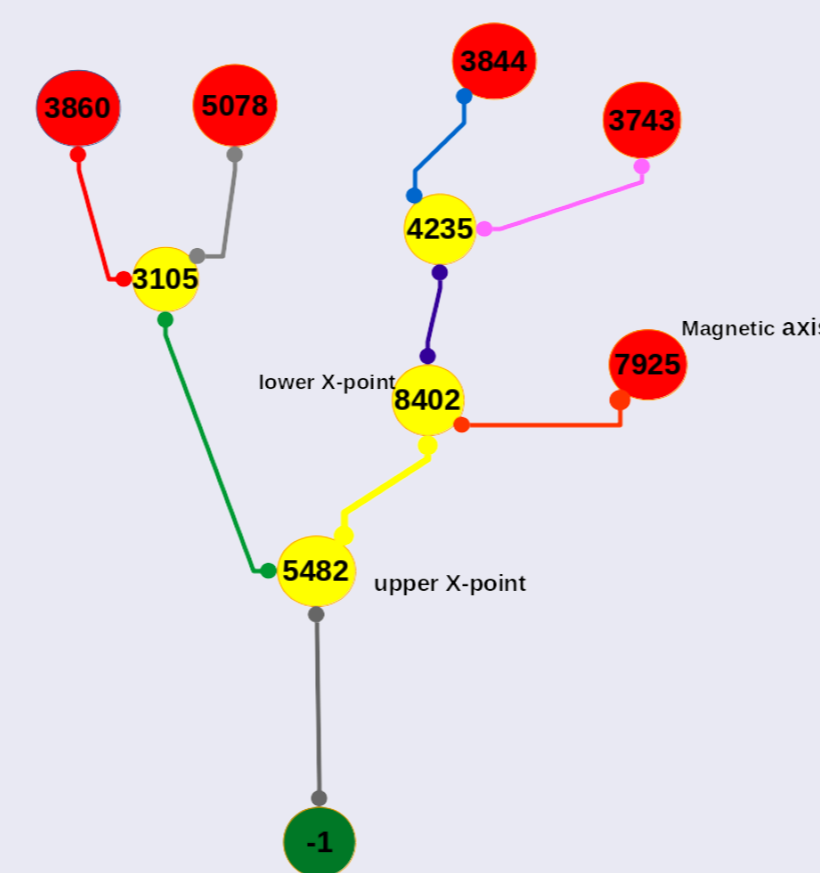
In 2-D
the only possible critical points of a Morse function are :
Maxima index = 2 Minima index = 0
Saddles index = 1

Topology of a Morse function : The topological set of the iso-contours of f consists of connected components that are either

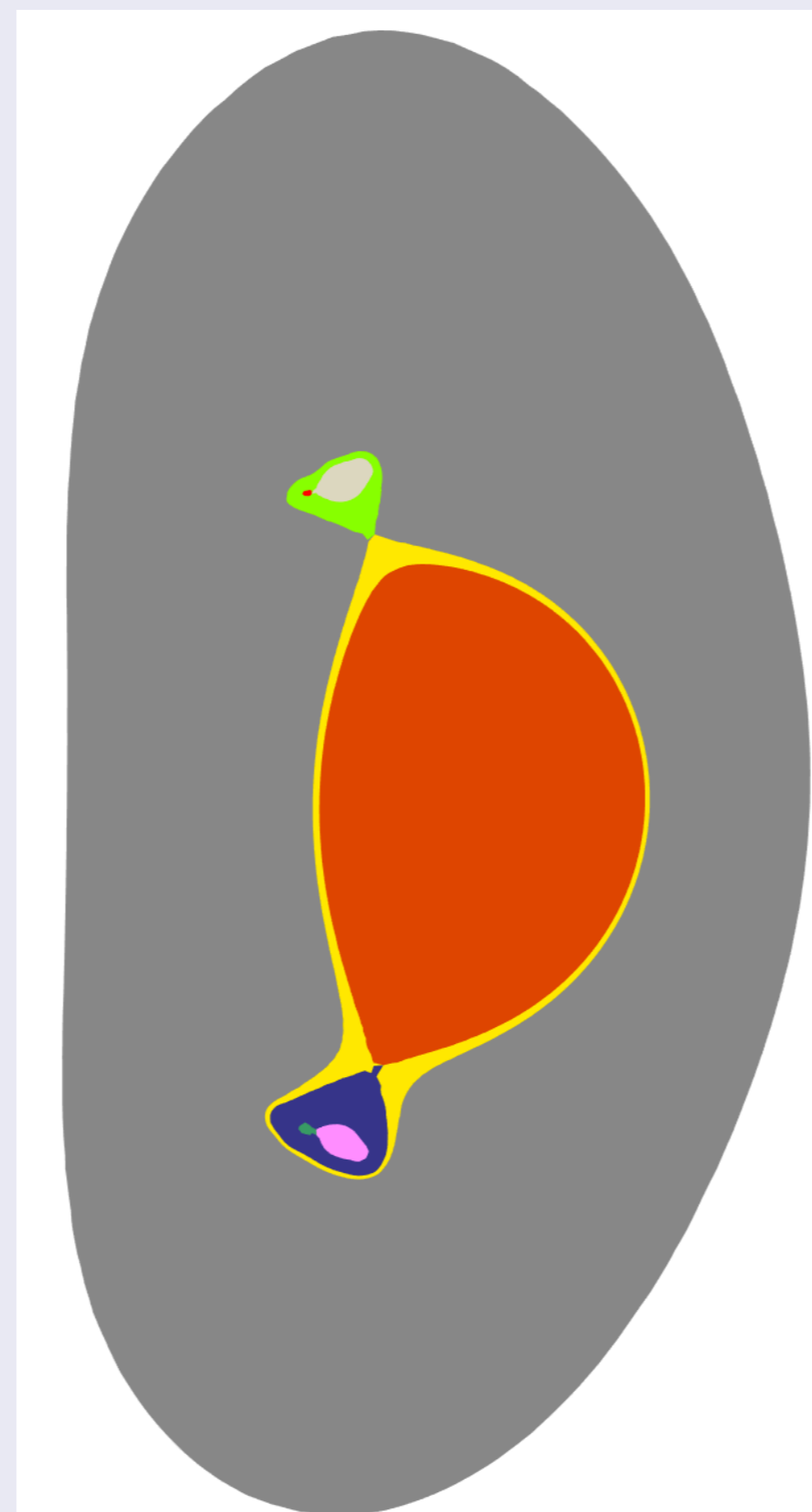
- Circle cells which are homeomorphic to open disks
- Circle bands which are homeomorphic to open annulus

The Reeb graph

- Compute the connected components by computing the Reeb Graph



- Obtain the associated domain segmentation



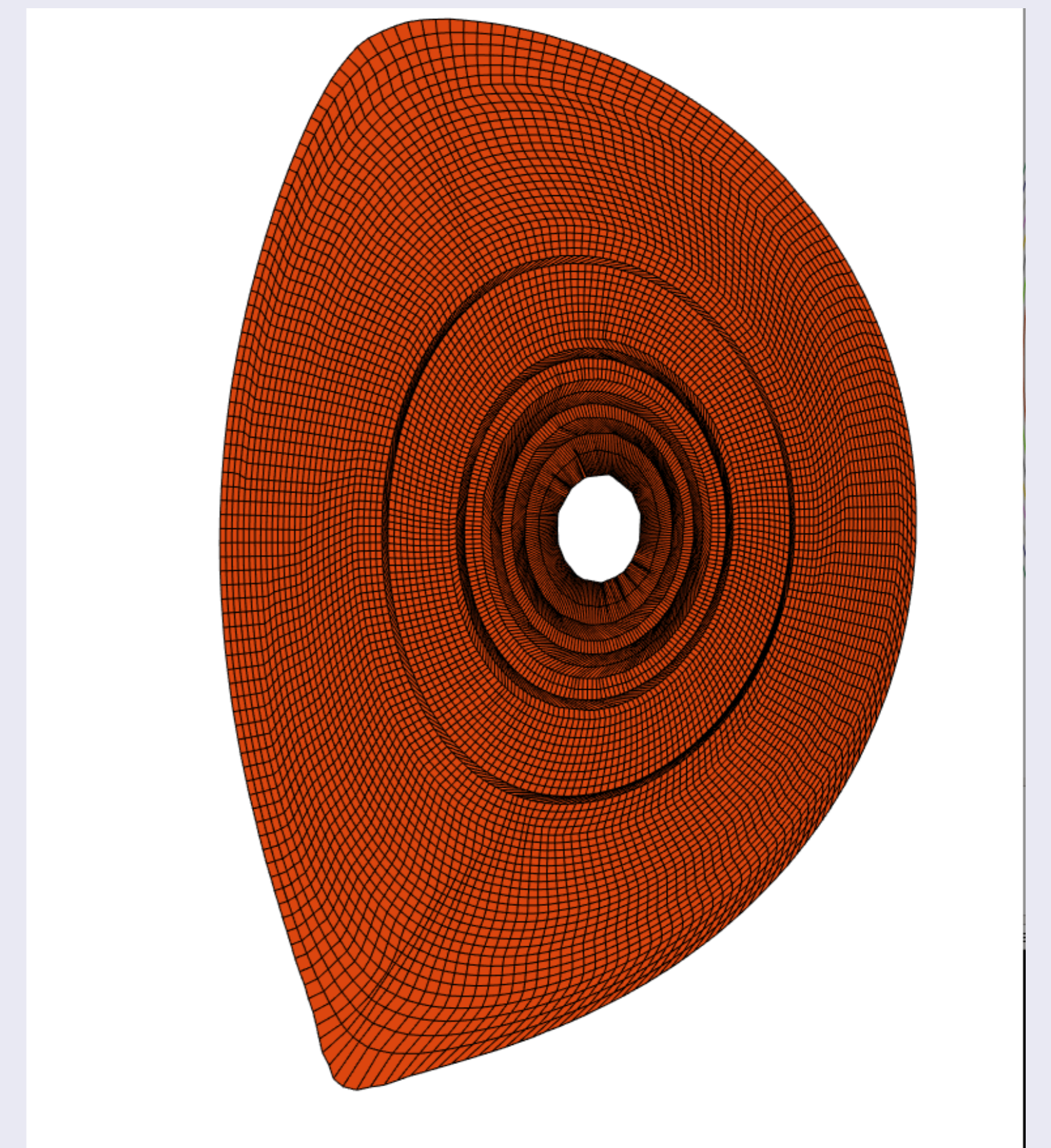
each subdomain correspond to an edge of the Reeb graph and in each subdomain, the function is monotone

Construction of the mapping of Ω_n

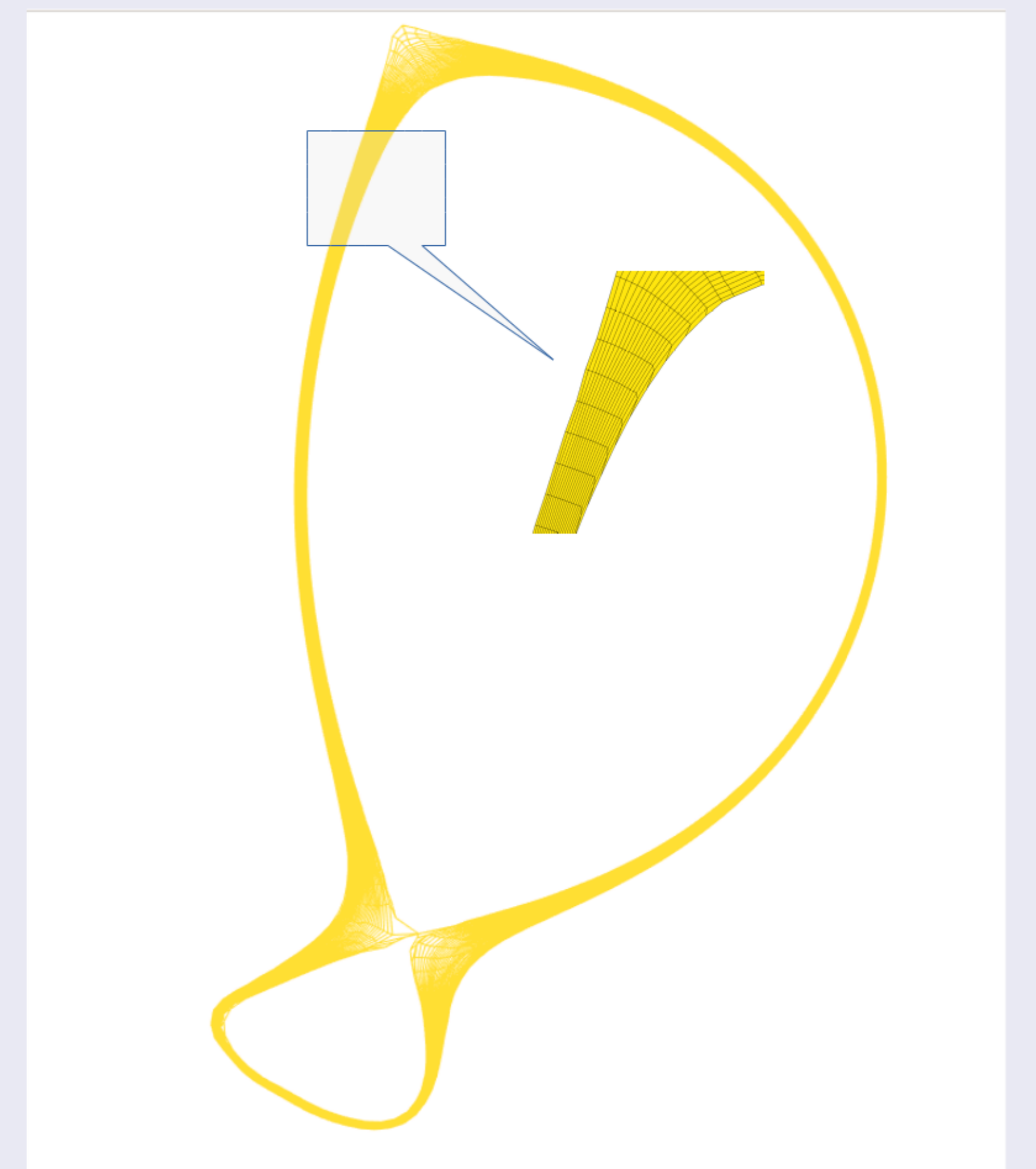
Orthogonal mesh constructed by intersecting

- The isolines
- Streamline integration of $\frac{dx}{ds} = \nabla \psi$

Leaf of the Reeb Graph : homeomorphic to a disk
Example : Reeb Graph edge : [7925-8402]



- Internal edge of the Reeb graph : homeomorphic to annulus
Example : Reeb Graph edge : [7925-8402]



Future works

- More accurate and smooth GS solvers
- Add additional mapping techniques : Elliptic solvers + equidistribution
- Topological simplification of the Reeb-Graph
- Construction of \mathcal{C}^1 mappings
- Take into account the vacuum chamber boundary